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Mangrove Density Analysis in Teluk Semanting Ecotourism Area using NDVI

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Abstract: The mangrove ecosystem is of critical importance as a coastal vegetation system, playing a significant role in maintaining environmental stability, supporting social welfare, and fostering economic growth. In Teluk Semanting, Berau, East Kalimantan, mangrove forests play a vital role in preventing erosion, mitigating abrasion, providing habitats for various fauna, and supporting sustainable livelihoods through ecotourism. However, the area's mangrove forests are under threat due to the impact of human activities. To monitor mangrove forest development and prevent further degradation, it is essential to assess changes in the spatial distribution of mangrove land cover. This study utilises Sentinel-2A satellite imagery and the Normalized Difference Vegetation Index (NDVI) algorithm to analyse the spatial and temporal dynamics of mangrove cover in Teluk Semanting during the period 2019–2023. The results indicate a substantial decline in the high-density mangrove category, from 844.93 hectares in 2019 to 676.00 hectares in 2023, while the low- and medium- density categories exhibited a significant increase in area. This indicates a shift in mangrove quality from high-density to medium- and low- density categories. Regression analysis demonstrated a strong positive correlation (R^2 = 72.43%) between NDVI values and mangrove canopy density observed in the field, thereby underscoring the reliability of satellite imagery for monitoring mangrove conditions. The study emphasises the necessity of continuous monitoring and the implementation of conservation strategies to ensure the preservation of the ecological and economic benefits provided by mangrove ecosystems. This is particularly pertinent given the area's designation for ecotourism, where inadequate management could have adverse effects on the local community and global environmental stability.

Keywords : mangrove density; NDVI; Sentinel-2A; linear regression

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Introduction

Mangrove forests are a distinctive type of vegetation that thrive in the moist and muddy environments of tropical coastlines. These unique ecosystems play a vital role in preserving environmental equilibrium and offer substantial social and economic benefits to local communities. From an ecological standpoint, mangroves act as a natural coastal defence, mitigating the effects of waves and tsunamis through their physical protection against abrasion and erosion. Furthermore, mangroves serve as a habitat for diverse fauna, encompassing both terrestrial and aquatic species. From an economic perspective, the development of mangrove ecotourism offers considerable potential to support environmental conservation while increasing the income of surrounding communities (Barbier, 2016; Barbier et al., 2011). Mangroves are increasingly regarded as carbon-rich ecosystems that are important to conserve and restore (Lavieren et al., 2019). Beyond their ecological and economic importance, mangroves are also believed to play a role in climate regulation by capturing and storing significant amounts of carbon, thereby helping to offset CO_2 emissions generated by human activities (McLeod et al., 2011; Siikamäki et al., 2012).

According to the National Mangrove Map, officially released by the Ministry of Environment and Forestry in 2022, Indonesia possesses 3,364,076 hectares of mangrove ecosystems, representing 20.37% of the global area. Berau Regency is one of the areas that contribute to mangrove development, with an area of 85,389 hectares spread across eight coastal sub-districts, including mangrove forests in the Teluk Semanting area (Sahri et al., 2013). The mangrove forests in Teluk Semanting Village have made significant contributions, especially in terms of preventing erosion and abrasion, providing clean water and fresh air, and acting as a shelter for various marine and terrestrial animals.

However, the mangrove forest in Teluk Semanting is experiencing various problems, as highlighted by the Yayasan Konservasi Alam Nusantara (YKAN) team in 2024, who stated that damage had occurred due to the opening of traditional ponds. In addition, the news page Antara Kaltim 2020 reported that mangrove skin stripping and other damage had been carried out by irresponsible neighbouring communities. In response to the ongoing destruction and degradation, the surrounding community has consented to the restoration of the mangrove forest area. Collaboratively, the government and the local community undertook the restoration of the mangrove forest through the establishment of a 741-hectare mangrove forest area in 2017. The community has since engaged in continuous recovery efforts, resulting in the replanting of 37,000 seedlings by 2024.

By 2023, the Teluk Semanting mangrove forest had evolved to a stage where it was designated as a sustainable ecotourism area by the Berau Regency Government, with support from YKAN. This initiative will contribute to the conservation of endemic Bornean animals, which are threatened by illegal hunting, fires and deforestation, while also enhancing fish and crab biomass. From a socio-economic perspective, the positive impact of mangrove forest ecotourism has been such that it has become the Regional Tourism Development Master Plan of Berau Regency 2016-2031.

To ensure the effective preservation of these environments, it is essential to monitor dynamic changes that occur in mangrove areas in Teluk Semanting. To this end, it is vital to observe changes in the distribution of mangrove forest land to prevent any damage. While manual monitoring can be conducted through direct mapping in the field, this method is inefficient due to the significant manpower and time requirements. In recent years, the development of observation technology using remote sensing imagery has accelerated rapidly. The utilisation of remote sensing imagery facilitates the efficient mapping of mangrove forests across diverse temporal periods, with various levels of desired resolution, thereby enhancing the efficiency and comprehensiveness of monitoring mangrove areas.

A particular type of remotely sensed data that has been found to be effective in the monitoring of mangrove areas is imagery from the Sentinel-2A satellite (Wang et al., 2018). The research indicates that Sentinel-2A images can provide accurate results with a success rate of 90%, achieved by using infrared and shortwave bands. A substantial body of research has demonstrated the efficacy of Sentinel-2A imagery in identifying mangrove areas within tropical regions, particularly when employing the Normalised Difference Vegetation Index (NDVI) algorithm. The NDVI algorithm has been shown to be highly effective in detecting and differentiating mangrove vegetation from other vegetation types due to its capacity to measure the difference in light reflected by healthy and degraded vegetation. The utilisation of the red and near-infrared (NIR) bands in Sentinel-2A imagery facilitates the acquisition of precise information regarding the distribution and health of mangroves in the tropics (Quang & Hoa, 2022; Hariyanto et al., 2023;Umar et al., 2023).

The present study has been conducted for the purpose of mapping alterations in the area of mangrove forest in Teluk Semanting between the years 2019 and 2023. The identification of mangrove areas was conducted using the NDVI (Normalised Difference Vegetation Index) algorithm, a method which has been proven to allow effective monitoring of vegetation. Observations were made by means of analysing annual time series data in order to identify patterns of change that occurred during the period under investigation. The results of this analysis are expected to provide useful information to prevent further damage, as well as support efforts to conserve mangrove forests in Teluk Semanting.

Data and Method

Study Area

Berau Regency is located in the north of the capital city of East Kalimantan and covers an area of 34,127.47 km^2. The topography of Berau Regency is characterised by a hilly terrain and a plethora of large and small islands, totalling 52. The abundance of islands in Berau Regency endows it with a wealth of coastal natural resources, including mangrove forests. The 80,000 hectares of mangrove forest in Berau regency represent the second largest in East Kalimantan. The present study focuses on the mangrove forest area of Teluk Semanting Village in Derawan Island District, Berau Regency, East Kalimantan Province, Indonesia. Teluk Semanting Village has an area of approximately 99.96 km^2. The predominant land cover is mangrove forest, which extends from east to west, encompassing an area of approximately 8.41 km^2 (Figure 1).

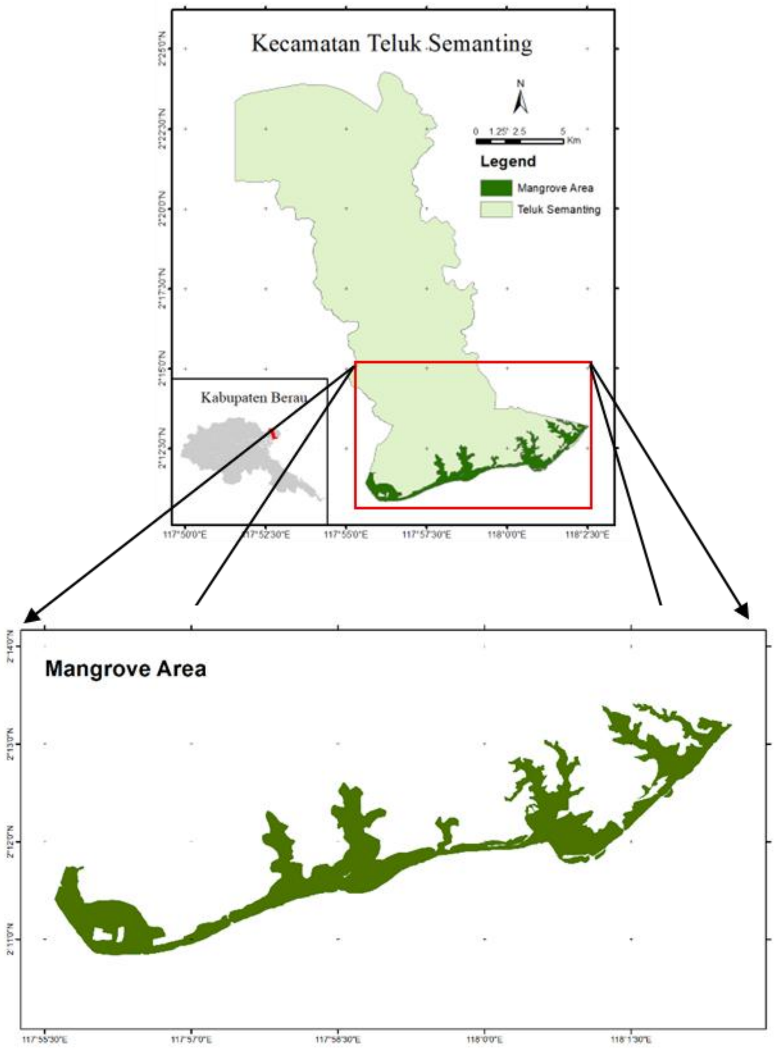

Figure 1. Mangrove Forest Area in Teluk Semanting

Data

The present research employs Sentinel-2A remote sensing data acquired from 2019 to 2023, with supporting data, including the administrative boundaries of the Teluk Semanting mangrove forest area, utilised as the study area boundaries. Image data processing is conducted using Google Earth Engine (GEE) software, with the processing initiated by pre-processing the data through filtering and cloud masking. The subsequent stage involves the cropping of the image according to the focus of the mangrove forest boundary area. The Normalised Difference Vegetation Index (NDVI) method is then applied to determine the mangrove vegetation cover and to assess the mangrove density (Figure 2).

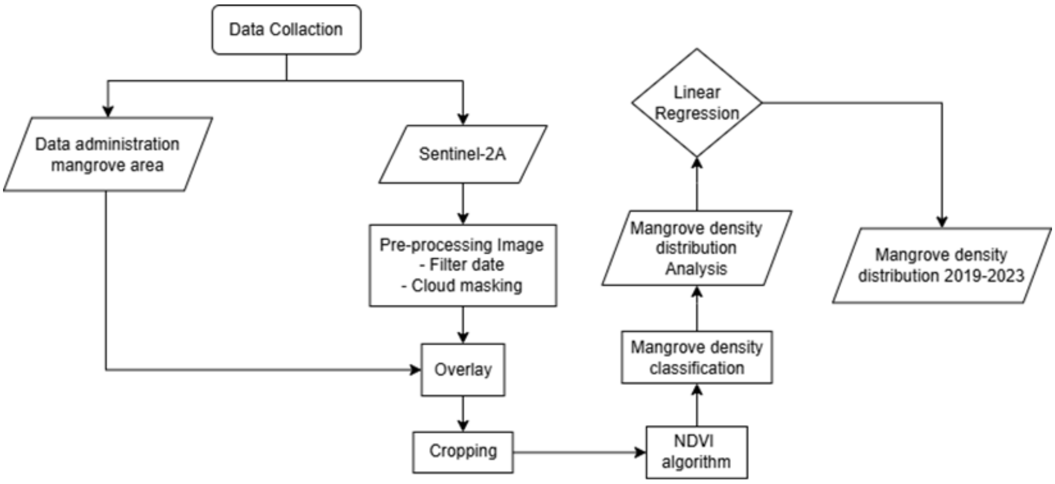

Figure 2. Flow chart illustrates the research method, which began with the collection of primary data, followed by the processing of images, application of the NDVI algorithm, mangrove density classification, and linear regression testing. This culminated in the determination of mangrove density distribution from 2019 to 2023.

NDVI

The Normalised Difference Vegetation Index (NDVI) is a metric used to detect differences in vegetation cover by comparing the absorption of red wavelengths by chlorophyll and the near infrared (NIR) reflectance of green vegetation (Huyen et al., 2022). NDVI values range from -1 to +1, with higher values indicating the presence of more vegetation and values around zero indicating areas with no vegetation. Negative values are usually associated with water or soil that is not covered by vegetation. The correlation of NDVI with green biomass, crown closure and leaf area index renders it a powerful tool for detecting vegetation health and density (Gitelson et al., 2003). The formula used in the NDVI algorithm is as follows:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The mangrove density map is categorised into four classes, with the red class designated as a water body with a range of -0.19 - 0.08, and the subsequent orange class categorised as a sparse mangrove class with a range of 0.08 - 0.31. The next class, marked in yellow, is categorised as a medium-density mangrove class, with a range of values from 0.31 to 0.48. The final classification, marked in light green, is categorised as a dense mangrove class, with a range of values from 0.48 to 0.67.

Ground Check

The field survey data were utilised to adjust the results of the density map to the actual situation, with the field surveys being carried out using the hemisperic photography method.A total of 30 photo samples of the mangrove canopy were obtained, distributed on the basis of each density class area, with each density class being sampled with up to 10 photos.The field survey samples were processed in the imageJ application to determine the percentage of mangrove canopy density pixels. However, factors such as sunlight and camera capabilities can influence the accuracy of the results, as the camera may be unable to capture objects that are either too bright or too dark. Furthermore, an excess of incoming light in a photograph can also lead to inaccurate results, while the presence of light barriers within the mangrove tree canopy can enhance the accuracy of the density measurements (Khakhim et al., 2018). The classification of mangrove density is categorised into three classes: dense, medium, and sparse. The dense class encompasses canopy coverages ranging from 60% to 70%, the medium class covers 55% to 60%, and the sparse class covers 50% to 55%.

Linear Regression

The regression analysis is a methodological approach employed to investigate the relationship between one variable (the dependent variable, also known as the explained variable) and one or more variables (the independent variable, also known as the explanatory variable).The regression test is utilised to evaluate and quantify the strength of the relationship between one variable (the independent/predictor) and another variable (the independent/dependent/responder). In instances where the independent variable is a sole entity, the regression analysis is designated as simple regression. In the case of multiple independent variables, the regression analysis is termed multiple linear regression, a term derived from the fact that there are several independent variables affecting the dependent variable. The linear regression method was utilised to test the relationship between the vegetation index (as the value of the independent variable x) and the percentage value of mangrove density in the field (as the value of the dependent variable y).The simple linear regression can be expressed mathematically as follows (Kurniawan, 2008):

$$Y = a + bX$$

Y = dependent variable (response)
X = free Variable (predictor)
A = constant
B = regression coefficient

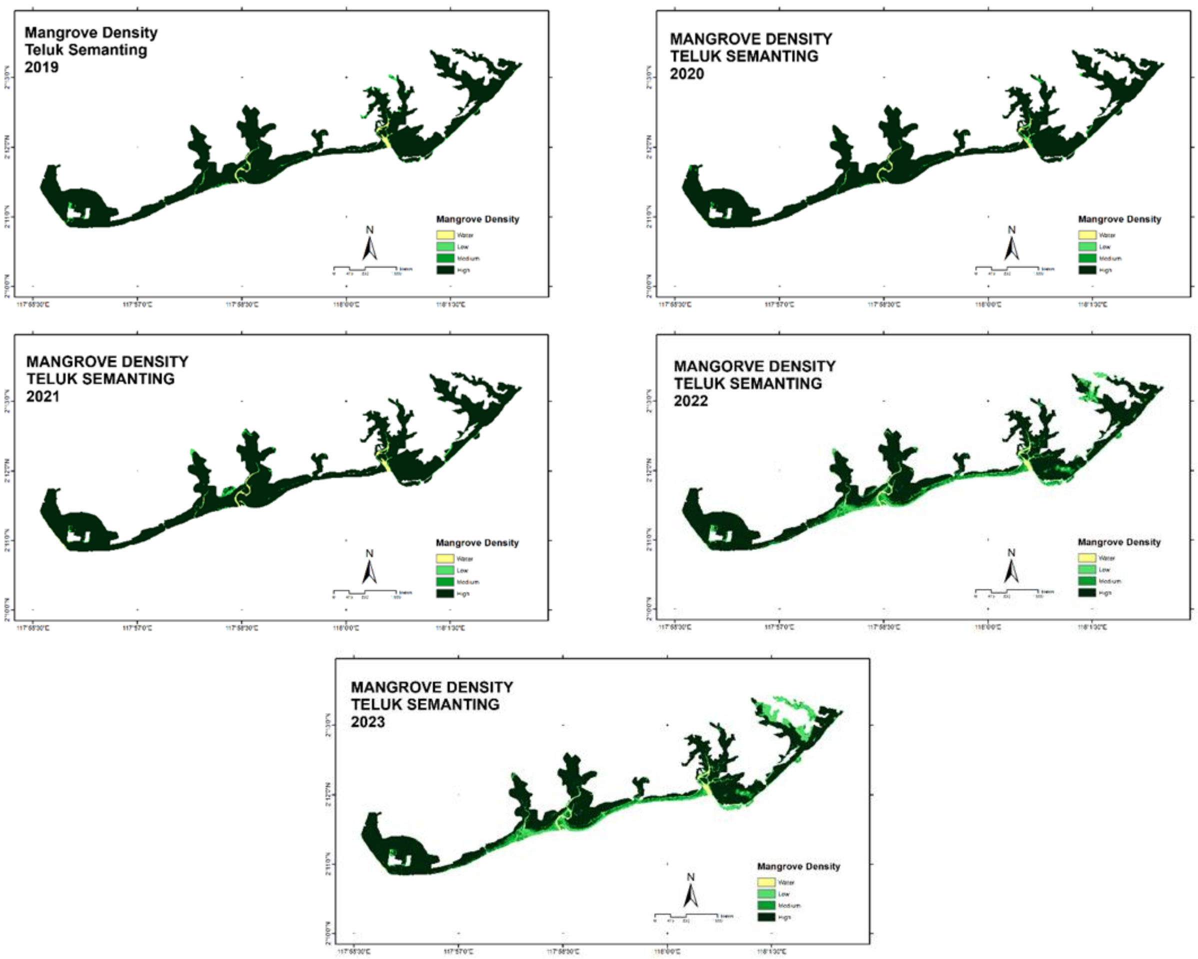

Figure 3. Map of changes in mangrove forest density in Teluk Semanting from 2019-2023

Results and Discussion

Mangrove Density

The mangrove forest density analysis was conducted utilising Sentinel-2A imagery, which underwent processing via the Normalised Vegetation Index (NDVI) algorithm. This algorithm is based on a combination of red and near infrared (NIR) bands, as outlined in Equation 1. The resulting mangrove density map was then classified into four categories: water class (range -0.19 to 0.08), low class (range 0.08 to 0.31), medium class (range 0.31 to 0.48) and high class (range 0.48 to 0.67). The resulting mangrove density distribution is visualised in Figure 3. The utilisation of green colour gradation in the visualisation serves to illustrate the mangrove density level based on the NDVI value. Dark green colours serve to indicate high NDVI values, reflecting areas with high mangrove density. In contrast, light green colours indicate low NDVI values, representing areas of decreasing mangrove forest density.

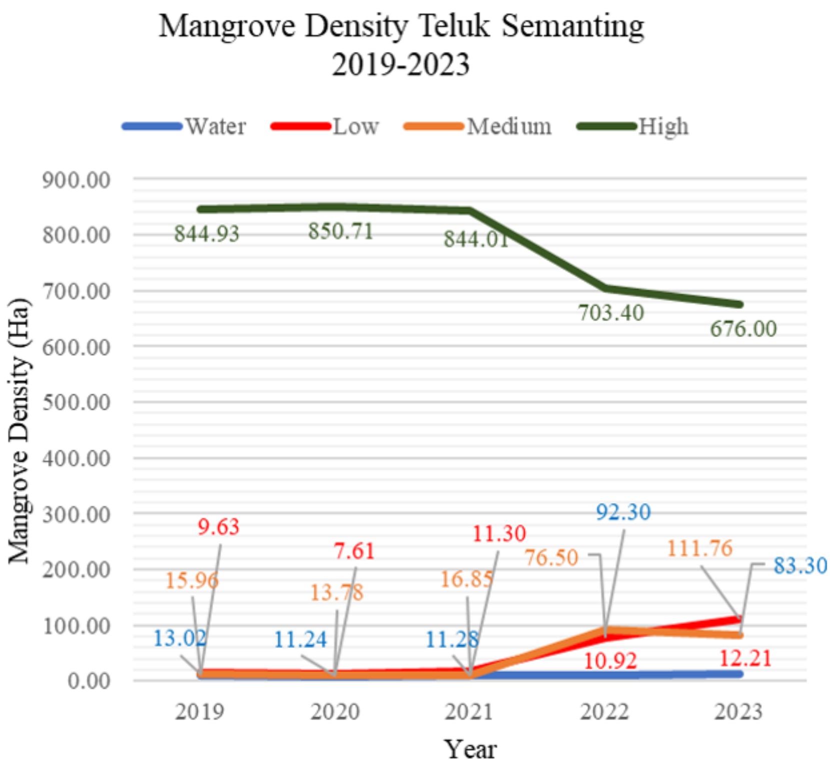

Figure 4. Mangrove density class change in Teluk Semanting in 2019-2023

The analysis of mangrove cover classification in Teluk Semanting during the period 2019-2023, when viewed on a graph, shows significant dynamics (Figure 4). The high category (see Table 1), represented by the green line, which dominates the mangrove cover, decreased from 844.93 ha in 2019 to 676.00 ha in 2023. The most precipitous decline occurred during the 2021-2023 interval, indicating a degradation of mangrove forests to 168.93 ha. Conversely, the low category, represented by the red line, exhibited a substantial increase in area, particularly in 2021 and 2023, when it surged from 16.85 ha in 2021 to 76.50 ha in 2023. This represents an increase of 59.65 ha. A similar increase was observed in the medium category (red line), with a notable rise between 2021 and 2022, from 11.28 ha in 2021 to 92.3 ha in 2022. In 2023, a decline was observed in the low category; however, the graph reveals that this decline was not statistically significant and tended to be more pronounced than in 2021.No substantial changes were evident between 2019 and 2021, which can be attributed to the ongoing maintenance of the mangrove forest through human activities. Conversely, the water area delineated by blue lines exhibits fluctuations, with an increase from 9.63 ha in 2019 to 12.21 ha in 2023, which may be indicative of shoreline changes or erosion processes in Teluk Semanting.

Table 1. Magrove classification in study area during 2019-2023 di Teluk Semanting Tahun 2019-2023

Classification	**Area (Ha) at Year #**				
	2019	2020	2021	2022	2023
Water	9.63	7.61	11.30	10.92	12.21
Low	15.96	13.78	16.85	76.50	111.76
Medium	13.02	11.24	11.28	92.30	83.30
High	844.93	850.71	844.01	703.40	676.00

Linear Regression

In this study, regression analysis is employed to ascertain the extent of the relationship between the vegetation index (x-axis) and the percentage value of mangrove density (y-axis) in the field. The objective is to analyze the correlation between the results of the mangrove density and the NDVI algorithm, to determine the relationship between mangrove density and vegetation index, based on the obtained data.

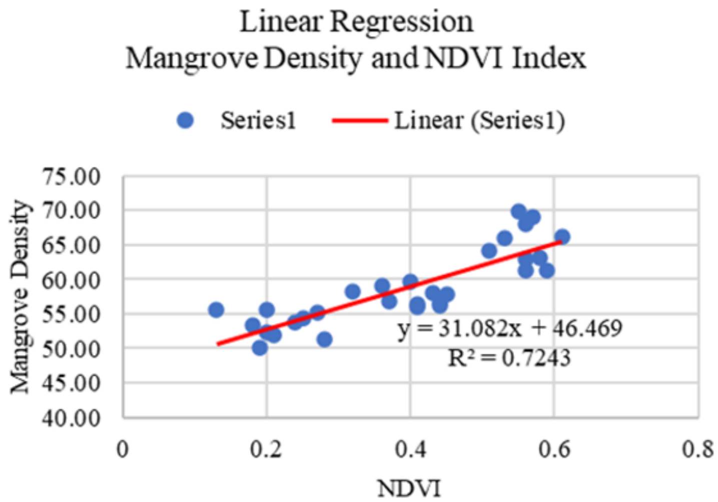

Figure 5. Linear Regression of Mangrove Density and NDVI Index

The value of the NDVI index, as determined by the sample points utilised in this study, will subsequently be compared with the percentage value of mangrove canopy density, as derived from the field survey results of 30 samples that have been processed, to ascertain the relationship between the two variables. The relationship between the percentage value of mangrove density from field surveys and NDVI values from image data is determined through linear regression tests (Figure 5). The value of the equation is y = 31.082x + 46.469, and the correlation between the two variables is 0.8473. The correlation results indicate a positive relationship, suggesting a strong correlation where an increase in the NDVI index corresponds with an increase in the percentage value of mangrove crown density. The R2 value of the results of this linear regression test is known to have a value of 0.7243, which means as much as 72.43%. The NDVI index of the Sentinel-2A image demonstrates a strong relationship with the value of mangrove density in the area, as evidenced by data analysis.

Conclusion

The analysis of mangrove covers in Teluk Semanting during the 2019-2023 period revealed substantial alterations, indicative of the dynamics of the mangrove ecosystem. The category of high mangrove cover exhibited a significant decrease in area, particularly in the 2021-2023 interval, while the low and medium categories demonstrated a substantial increase during the same period. This phenomenon indicates a degradation of mangroves from high quality to lower quality, which may be caused by human activities, land conversion, or other environmental pressures. Linear regression analysis, showing a positive relationship with a coefficient of determination of 72.43%, confirms that the data obtained is of high quality and can explain most of the variation in mangrove cover dynamics.

Teluk Semanting Mangrove Forest plays a pivotal role in maintaining global environmental stability through its functions in carbon storage, protection against erosion and abrasion, and preservation of fauna ecosystems. Furthermore, its designation as an ecotourism area has a positive impact on the socio-economic conditions of the surrounding community. However, the dynamics identified indicate significant challenges to the sustainability of this area. A decline in mangrove quality and density, if not addressed, could threaten ecosystem functions and ecotourism benefits in the future. Therefore, continuous monitoring and improvement is needed to ensure that this area continues to provide ecological and socio-economic benefits, while maintaining environmental balance in Teluk Semanting.

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